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Influence of Rainfall Movement on Peak Discharge in Urban Sewers

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Calculations have been made in order to evaluate the effect of rainfall movement on peak discharge. The 25 extreme events have been selected from a long historical rain series from a single rain gauge. The rains have been simulated to move with the recorded speed and direction of the rain across an artificial, elongated catchment positioned in 8 different directions. A real catchment layout was also investigated. The paper investigates the effect of longitudinal movement. Laterally, the rain is assumed to be uniformly distributed.

Calculations were made with the MOUSE-program, modelling runoff using the dynamic wave approach. An additional program was developed to simulate the moving rain input. Peak discharge in the sewer system with and without rainfall movement was treated statistically in terms of return period and compared.

The movement of the rain is not important from a statistical point of view (up to 5 %), but for individual events the effect may be significant (at least up to 19 %). The result is restricted to the effect of longitudinal variation in time and space. The effect of variation lateral to the movement may be much bigger, increasing with size of catchment.

The artificial catchment with flow direction towards NE gives the greatest increase in the $Q_{\max}$ and *vice versa* with the catchment orientated towards SW. This is due to wind direction from the SW being the most frequent in Denmark. The effect of rainfall movement is smaller for the real catchment with sewers in many different directions.

Introduction

More than a century ago the first choice of parameters for characterization of rain was made. It was a very wise choice: The *intensity* of a rain was assumed to be uniformly distributed over a given *duration*, selected for given *frequency.* Since then more detailed descriptions have been attempted for the synthesis of the *design storm*. These more detailed descriptions involved the distribution in time and space. Two trends have manifested themselves: The standardized temporal distribution and the areal reduction factor, Arnell *et al.* (1984). Both can be considered modifications to the design storm concept. Neither concepts have lead to clarification, nor caught on in general to the engineering practise of urban storm drainage. These concepts have been attempted to include »the moving storm« without succes.

With the introduction of computer technology the need to synthesize the rain events of a long rain series into »design storms« has disappeared, Johansen and Harremoës (1975), Harremoës *et al.* (1984), Henderson (1986). Now we can use the rain events as in fact they were measured, as input to the calculations. In this way we can test the design of a system by finding the return period of the detrimental effect, like flooding or extreme pollution, Johansen *et al.* (1984). This is different from finding the return period of a »design storm«, the frequency of which is different to the return period of the detrimental effect, Sieker (1978).

In this study the concept of historical rain series is applied. The analysis of the moving storm is done with the rain events as they were recorded – including the direction and speed of the movement of the clouds – and compared with the traditional approach, same rain events without movement. The paper is limited in scope to application of data from a single rain gauge, accounting for the longitudinal variation along the path of the rain. The implied assumption is uniform distribution, lateral to the movement.

Rainfall Kinematics

Long rain records are available from rain gauges only. It is a point measure providing no information on the movement of the rain nor the geographical distribution. From such point measures a set of design storms are generated. Numerous references could be quoted for analyzing »the moving rain effect« by selecting either a design storm or a rain as measured for analysis by varying the direction and speed of that rain relative to a particular catchment.

Varying the movement poses the analyser with a dilemma. Fig. 1 shows a rain as recorded at the gauge. It starts to rain at time t1 and stops at time t2. The duration is T. The speed of movement is v. The rain distribution along the path of the rain is also shown in Fig. 1. The length of the rain is L. It applies that $L = v\ T$. When

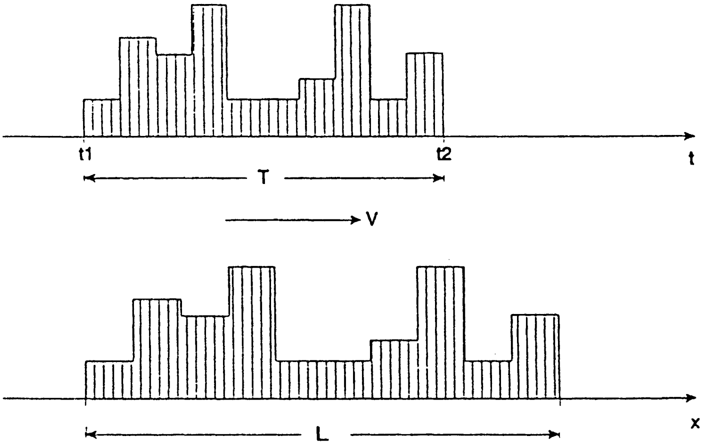

Fig. 1. Recorded rain.

analyzing the effect of movement the features have to be selected for the analysis.

The analyzer has a choice of principle:

1) To keep the length L = constant. This implies that the rain geography is constant, while the speed varies.
2) To keep the duration T = constant. This implies that the rain geography varies with the change in speed.

In the first case the duration of the rain increases with decreasing speed. It is the same rain geographically, but it is not the same rain record at the gauge. In the second case the length decreases with decreasing speed. It is the same recording at the gauge, but it is not the same rain geographically.

There is no solution to this dilemma. There is no physical principle with which to make the right choice. When the rain was recorded, it did have the speed v. For a recorded rain all other choices are synthetic. Why not analyze on the basis of the rain series, including the recorded movement, as a realistic alternative.

In spite of this, numerous studies have been made to find the effect of movement by variation of the speed for recorded rains. The result depends on the selection of parameter variation, T or L constant. There is no way of knowing, what the right answer is.

The »design storm« is synthesized from the rain series without regard for the actual movement of the individual rain recorded. There is no way of finding a rationale for the allocation of a movement to a design storm.

The solution to the investigation of the effect of movement is to use the speed and direction of the historical rain as it was recorded. It is a specific feature of the individual rain; just as other features, like intensity distribution, duration, length etc. Accordingly, the effect is analyzed with the features of the historical rain record. Recently this approach has also been advocated by Niemczynowicz (1989).

The historical rain series approach gains increasing recognition for advanced analysis of performance of urban drainage structures. However, the *i-d-f*-curves and simple design rains are still suitable for simple design problems.

The Rainfall Movement Approach

The methodology of this study is basically very simple. Two calculations are made: a traditional calculation with the same, measured hyetograph in all inlets and a calculation where the hyetographs are displaced in time according to the movement of the rain event.

The following assumptions have been made:

- the shape of the rain does not change during the movement
- the intensities are uniform in the direction lateral to the direction of movement
- the speed and direction of the rain is constant for the period observed.

If these assumptions are fulfilled, every rain gauge will show the same hyetograph – except for a displacement in absolute time of the hyetograph, depending on the position of the gauge and the movement of the rain.

The actual movement of the rainfalls considered is not known, but the wind at 700 mbar altitude has been shown to give good approximation to rain speed and direction (Marshall 1980, Niemczynowicz 1984). Wind data at 700 mbar from the Danish Meteorological Institute has been used to describe the rainfall movement.

For the calculations a historical rain series of data covering 9 years has been used. The data are point measurements from one gauge. The 25 most extreme events have been selected and used for the actual calculations.

Artificial Catchment

The artificial catchment used for the simulations is a simple rectangularly catchment with dimensions 30 m × 2,600 m, Fig. 2. The drainage system was designed to have full pipe flow with a return period of 2 years according to accepted design rules. The downstream boundary condition was chosen as a free outlet in order to avoid backwater.

In order to examine the peak discharge as a function of the main direction of the artificial catchment, it was positioned in 8 directions as shown in Fig. 3. For events without surcharge the system was also used to detect differences in peak discharge as a result of different catchment length. This was simply done by using results for different pipes as shown in Fig. 2.

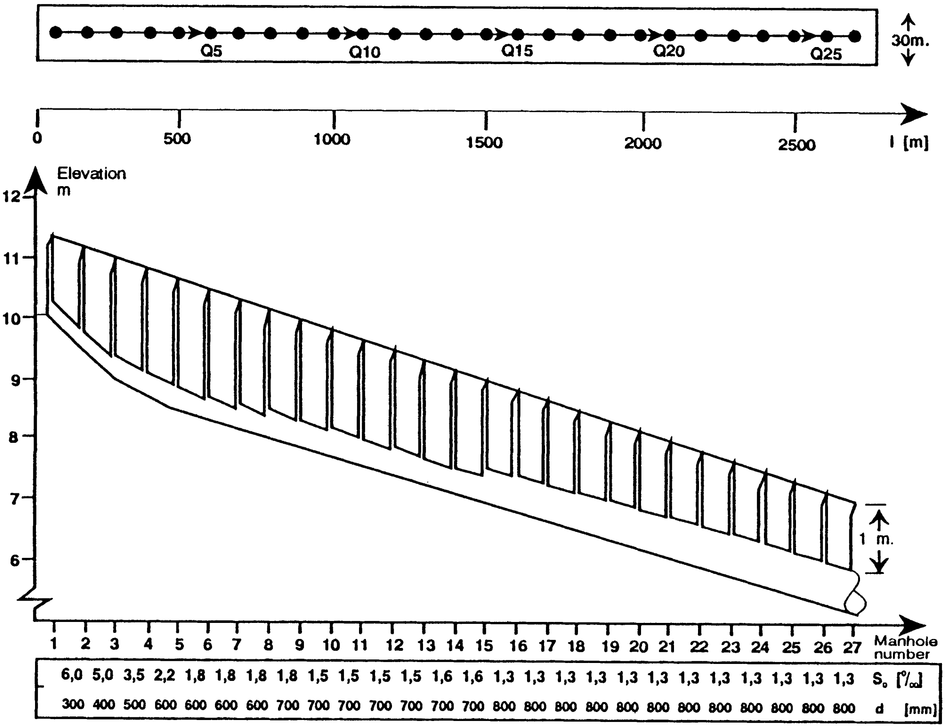

Fig. 2. Artificial catchment.

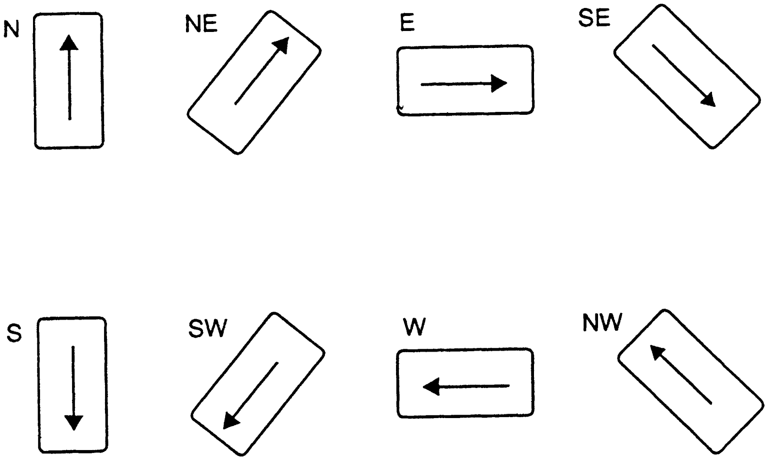

Fig. 3. Artificial catchment rotated into 8 directions. Catchment identification refers to flow direction.

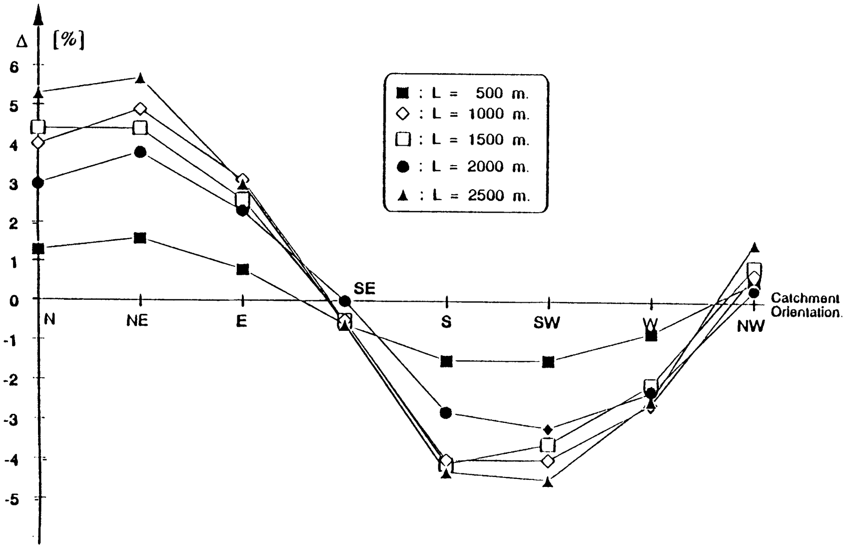

Fig. 4. $Q_{\max}$ as a function of catchment length and orientation.

Results of Computations

The deviation (Δ) of introducing the movement is defined as follows

$$\Delta = \frac{Q_{\max,\mathrm{mov}} - Q_{\max,\mathrm{stat}}}{Q_{\max,\mathrm{stat}}} \; [\%]$$

The stationary result is considered as basis because this is the result derived from the traditional approach. Δ shows whether the introduction of rainfall movement is significant or not.

The artificial catchment have deviations for the 25 events between −15 % and +19 %. The variation is greatest for the longest catchment, but even the shortest (500 m) shows a range of ±7 %.

When statistical analyses is applied to the results, a pattern is turning up. It is possible to detect a difference in Δ depending on the the orientation of the catchment. In Fig. 4 the average deviation for the 25 events are shown as a function of catchment length and orientation. This shows that the discharge is greatest for the catchment orientated towards NE, and *vice versa* for the catchment orientated towards SW. This is closely connected to the dominating wind direction in Denmark, which is towards NE.

The average deviation is slightly increasing with increasing catchment length, but even for the longest catchment (2,500 m) it is not more than ±5-6 %.

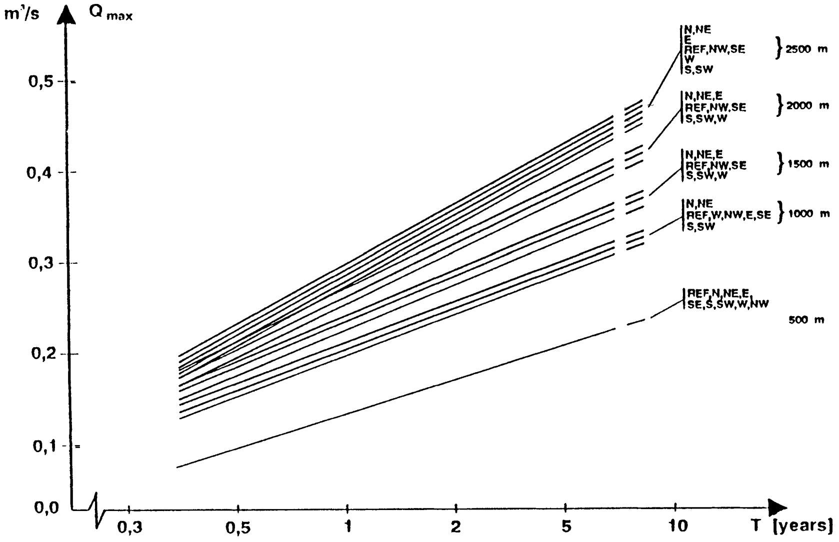

Fig. 5. Q_{max}-log$T$ diagram for all catchments.

The best statistical treatment of the results is to rank them for each catchment and find the best fit on a plot of Q_{max} as a function of return period $Q_{max} = f(\log T)$. The resulting lines are shown in Fig. 5.

The lines for moving rain and for stationary rain were compared. If the difference was found not to be significant the estimates of the lines were combined to a common estimate (covariance analysis). This is the reason why there is a different number of lines for each catchment length in Fig. 5.

The difference in calculated Q_{max}-value for a given length and return period is small (up to 5 %) compared to all the other uncertainties in the calculation procedure.

Evaluation of the Effect of Rainfall Movement

For practical purposes the comments are split into two different situations:

- situations where the effect is related to an overall performance
- situations where the effect of individual events is important.

In the first category the significance of movement is related to the statistical effect, which was found to be up to 5 %. This effect is even smaller for a real catchment with branches and shifting sewer directions. Accordingly the rainfall movement is insignificant for the peak discharge for situations where the interest is of more general character - for instance, when new systems are designed.

In the second category the significance is related to results from the individual events. These show significant variation. It is therefore impossible to give an overall conclusion for the effect. This also means, that it can be of importance to include the rainfall movement in calculations, when the result from every individual event is of interest – for instance, in case of investigation of peak discharge from a particular event.

A Case Study

A small catchment in Birkerød, Fig. 6, has been selected for a case study. The main difference compared with the artificial catchment is, that this catchment is branched. It still has a dominating flow direction (towards NE). The length of the system in this direction is approximately 800 m.

The greatest deviation is $\Delta = 3.1\,\%$ for an individual event. When statistical analysis is used there is no effect.

This does not necessarily mean that the rainfall movement is insignificant for all real catchments. The Langedam catchment is quite small, and even though the system has a dominating flow direction many of the pipes have other directions. A longer and less branched catchment would of course have effects closer to those of the artificial catchment.

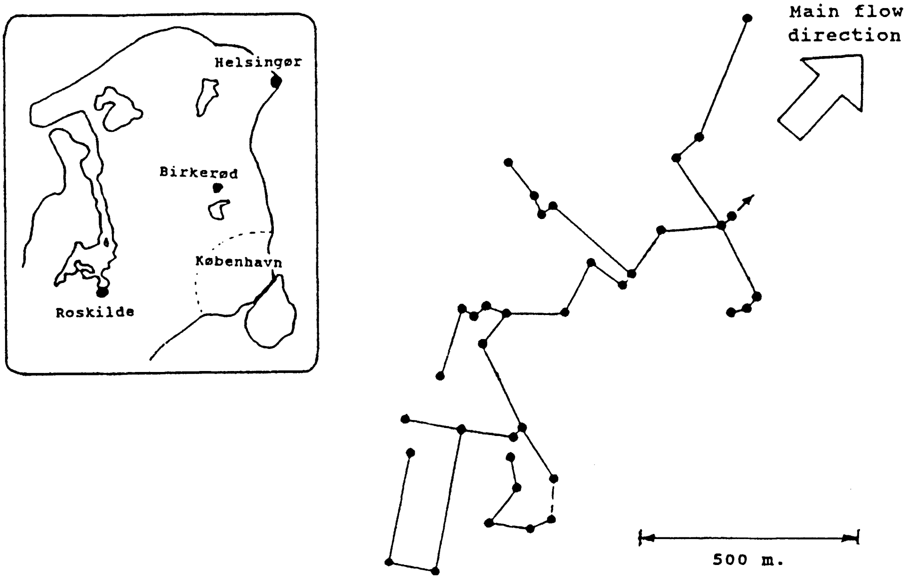

Fig. 6. Langedam catchment in Birkerød.

Conclusions

The results show that the rainfall movement statistically gives little to no effect (up to 5 %) for any of the catchments considered. The artificial catchment gives the greatest increase in $Q_{\max}$ when it is directed towards NE and *vice versa* when it is directed towards SW. For real catchments with sewers in many different directions the effect of rainfall movement is even smaller. It can be concluded, that the rainfall movement has no practical importance to extreme peak discharges for a given return period. Thus it is of no significance to the design situation. This conclusion applies to longitudinal variations, but variations lateral to the the movement may be significant.

For individual events the effect of rainfall movement can be much bigger (at least up to 19 %). Depending of the rainfall and its movement, the effect can vary a lot for the same catchment. It is therefore impossible to give an overall conclusion for the effect for individual events for a given catchment. But it may be stated that the effect of rainfall movement increases the longer and less branched the catchment is. The variation in the effect means that movement should be taken into account in situations where an individual event is of interest, unless the catchment is small and branched.

References

Arnell, V., Harremoës, P., Jensen, M., Johansen, N. B., and Niemczynowicz, J. (1984) Review of rainfall data application for design and analysis, Wat. Sci. tech. 16, pp. 1-45.

Harremoës, P., Jensen, M., and Johansen, N. B. (1984) A staged approach to Application of Rainfall data to Urban Runoff Calculations, Wat. Sci. Tech. 16, pp. 237-250.

Henderson, R. J. (1986) Rainfall Time Series for Sewer System Modelling, WRC Engineering, rep. ER 195E, Swindon, UK, July 1986.

Johansen, L., and Harremoës, P. (1975) Dimensionsgivende regnskyl under hensyntagen til intensitetsfordelingen (Design rain and rain series with variable temporal intensity distribution), Nordisk Symposium om kvantitativ urban hydrologi, Sarpsborg, Norge.

Johansen, N. B. *et al.* (1984) Methods of calculation of Annual and Extreme Overflow Events from Combined Sewer Systems, Wat. Sci. Tech., 16, pp. 311-325.

Marshall, R. J. (1980) The estimation and distribution of storm movement and storm structure using a correlation analysis technique and raingauge data, *Journal of Hydrology, Vol. 48,* pp. 19-39.

Niemczynowicz, J. (1984) An investigation of the areal and dynamic properties of rainfall and its influence on runoff generating processes. Institutionen för teknisk vattenresursläre, Lunds tekniska Högskola, Lund, Sweden.

Niemczynowicz, J. (1989) Multi-event Moving Storms as an Areal Rainfall Input derived from Point Measurements, Int. Conf.: Topical Problems in Urban Storm Drainage, Strbske Pleso, Czechoslovakia, April 1989.

Sieker, F. (1978) Investigation of the accuracy of the postulate total rainfall frequency equal flood peak frequency, Proc. 1' Intl. Conf. on Urban Storm Drainage, University of Southampton, Pentech Press, London, U.K. pp. 31-41.

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